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UNFULFILLED TECHNOLOGY NEEDS IN SPACE POWER SYSTEMS

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National Aeronautics and Space Administration

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ABSTRACT

The purpose of this paper is to define the major power system technology development needs related to the solution of currently existing problems, as opposed to those related to new requirements anticipated for future space missions. The results were obtained from an extensive review of past and present problems experienced in spacecraft development and flight. A major portion of the review derives from the deliberations of a Power Subsystems Panel, comprised of representatives from both government and industry, at the Flight Technology Improvement Workshop sponsored jointly by the Office of Aeronautics and Space Technology and the Office of Space and Terrestrial Applications of NASA Headquarters, July 31–August 2, 1979.

During the Workshop the identified problems were initially listed and categorized by technical area. They were then translated into terms of technology development requirements and consolidated where commonality was found. From these requirements, a set of ten specific recommendations for technology development was formulated.

These recommendations reflect currently unfulfilled technology needs which must be addressed, not only because of the need to solve major recurring power system problems experienced in the development and flight of current spacecraft, but also, and most importantly, because the technology development need, if not fulfilled, will become significantly aggravated in the future as higher power, longer life spacecraft with more sophisticated instruments become necessary.

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IN SPACE POWER SYSTEMS

INTRODUCTION

Research and development (R&D) programs derive from a wide variety of motivations, ranging all the way from satisfying basic curiosity to meeting critical necessities. Regardless of the motivation, however, there are two primary paths leading to the definition of most R&D programs. On one of these paths, a future position (goal, mission) is projected and the technology requirements to attain that position are determined. The technology requirements are then compared to the state of the art, gaps are identified, and finally, an R&D program is defined to fill the gaps. On the other path, the state of the art is addressed in terms of existing problems. The problems are sorted out; those due to technology inadequacies are identified; and finally, an R&D program is defined to overcome the inadequacies. See Figure 1.

There is a natural inclination to emphasize the first path because it is a forward-looking path. However, the second path, leading to the solution of existing problems, is frequently equally critical and equally challenging. This is especially true where the solution of current problems is also in a direct line with future technology requirements. In other words, the paths are not independent; the state of the art includes the existing problems, and technology requirements for the future often include the requirement for solution of existing problems.

It is important that appropriate consideration be given both to current problems and to future requirements in the definition of an R&D program. There have been many Symposia on technology for future applications[1,2] and on current state of the art,[3,4,5] but relatively few that emphasize

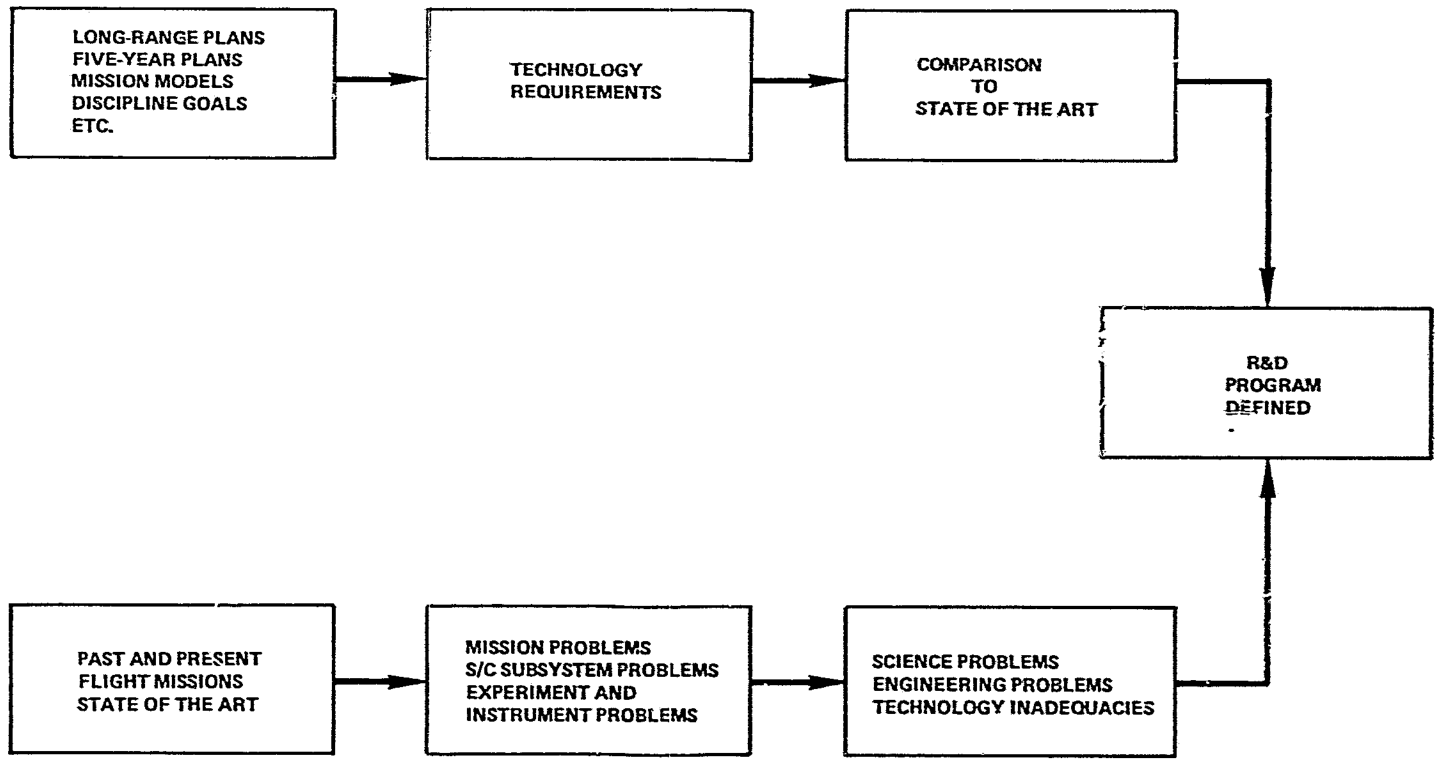

Figure 1. Paths to R&D Program Definition

current problems. To obtain this emphasis, the Office of Aeronautics and Space Technology and the Office of Space and Terrestrial Applications, NASA Headquarters, jointly sponsored a Flight Technology Improvement Workshop(6) at the University of Maryland from July 31 to August 2, 1979, specifically to discuss past and present spaceborne instrument and spacecraft subsystem deficiencies and shortcomings and to recommend potential corrections and technology developments to offset the occurrence of such problems in the future.

The workshop was organized into four panels covering specific problem areas: Optical Radiometric Instrumentation and Calibration, Electromechanical Subsystems, Attitude Control and Determination, and Power Subsystems. A series of technology recommendations for near-term consideration was developed by each of the panels. This paper presents the results of the discussions and deliberations of the Power Subsystem Panel which consisted of a cross-section of space power specialists from NASA, DOD, COMSAT, and industry. Panel members are listed in Table 1.

OBJECTIVES

The objectives of the Power Subsystem Panel were:

- To identify power technology needs that have become apparent through a review of problems that occurred on past and on-going spacecraft, as opposed to needs for potential future spacecraft

- To recommend a technology development program to accommodate the identified needs.

Although the spacecraft power subsystem was emphasized, these objectives also encompassed experiment and instrument power supplies.

Table 1
Power Subsystem Panel

NAME	ORGANIZATION
L. Slifer (Chairman)	NASA-GSFC
L. Randolph	NASA-OAST
F. Ford	NASA-GSFC
J. Westrom	NASA-GSFC
J. Miller	NASA-MSFC
E. Kelsey	NASA-LARC
R. Barthelemy	WPAFB-APL
J. Winkler	NRL
H. Killian	Aerospace Corp.
M. Swerdling	JPL
W. Billerbeck	COMSAT Labs.
S. Silverman	Boeing Aerospace
H. McKinney	Ford Aerospace
S. Peck	General Electric
J. Hayden	Hughes Aircraft
M. Imamura	Martin-Marietta
P. Nekrasov	RCA
R. Sparks	TRW

APPROACH

The overall approach was composed of the following three basic steps:

- Identify technology problems encountered in recent systems

- Translate the technology problems into technology development requirements

- Prioritize the technology development requirements to establish a basis for NASA planning and work recommendations.

Technology problem identification was derived from two sources. The major source elements were working papers prepared by each panel member describing specific problems encountered by his particular organization wherein technology improvement could have either avoided or minimized the problem. The thrusts of these papers were to:

- Identify various problems and inadequacies in past and ongoing spacecraft power system design, test, integration, and operation

- Define necessary solution(s) via supporting technology development work required.

A complete set of papers was provided to each panel member for review prior to the workshop. At the workshop the papers were presented and discussed in detail. The specific technology problems identified from these presentations were too numerous to itemize individually here; however, at the workshop they were listed under the following general power technology areas:

- Power System
- Solar Array
- Battery

- Power Distribution (switching, fault protection, cables, high voltage)
- Power Conditioning Electronics
- High Voltage Power Supplies
- Power Transfer (de-spun array to rotating spacecraft)
- General Problems (data, qualified parts, etc.)

Working papers prepared by members of the other workshop panels provided a secondary source for problem identification. In those papers two types of problems were identified. First, those due to interactions between the power subsystem and other subsystems or experiment and instrument sensors, and second, independent problems which are common to the power subsystem as well. These are shown in Table 2.

Using the complete listing of problems identified from both sources, the panel defined the technology needs and the engineering tool improvement needs required to solve or eliminate each of the problems. By translating the technology problems into technology development requirements, it was possible to combine them into a smaller, more manageable set to be used as a basis for the technology development recommendations.

Up to this point special care had been taken to avoid any sense of prioritization. However, the panel had been requested at the beginning of the workshop to restrict its recommendations to only those items that it felt were of the most urgent nature to carry out the spacecraft programs being considered for the reasonably near future. This request was based on the recognition of practical limits of manpower and funding resources. At this stage, then, it was necessary to initiate a prioritization of the technology development requirements. The prioritization process was readily

Table 2
Related Problems Identified by Other Workshop Panels

AREA	PROBLEMS
Attitude Control Subsystem	1. Power supply oscillation
	2. Stability of power to deflection coils of star tracker
	3. Flexible structure dynamics
	4. Array drive stepping
	5. Array blockage
	6. Particle contamination in components
	7. Component shorts
	8. Gap between feasibility demonstration and production
Electro-Mechanical Subsystems	1. Array deployment and orientation
	2. Slip ring - brush power and data transfer
	3. High voltage arcing and corona discharge
Experiment/Instrument Sensors	1. Noise on power bus
	2. Outgassing from other components

accomplished with general panel agreement and without the need for any minority report. However, it is important to recognize that this process results in two major effects. First, some technology improvements that are needed, or at least highly desirable, are eliminated from further consideration and second, those items at the bottom of the remaining limited priority listing are still from among the most important items of the initial listing.

Finally, the resultant prioritized listing of technology development requirements was summarized in the form of recommendations, the rationale for the recommendations, and the payoff to be obtained from accomplishment of the recommended work. In all, there were ten specific recommendations made by the panel. They are stated and discussed in the following section.

RESULTS - PANEL PRIORITY RECOMMENDATIONS

Analytical Modeling of the Power System

Provide accurate ac/dc analytical modeling of spacecraft power systems by developing models for the components, especially the solar array and battery, and synthesizing the component models into a system model. Within this recommendation, the definition of necessary parameters for electronic simulation of the ac solar array model is required.

Existing full-up analytical power system models are inadequate. Furthermore, as the power system grows in complexity, the design and power management problems are amplified. Coupling this with extreme complications for complete end-to-end checkout of the power system implies that use of this tool is becoming a mandatory requirement for understanding and predicting performance margins.

In particular, accurate dc and ac models of each power subsystem component are required. Such models presently do not exist for solar arrays and batteries. Needed is a detailed analytical model of the ac (transient and small signal ac) performance for solar arrays. Immediate problems on Tiros-N, Dynamic Explorer and Solar Maximum Mission that are related to the inability to test large arrays demonstrate the need for such models. Large arrays are too large to deploy and illuminate, and lightweight structures may even be too fragile to deploy in the presence of gravity.

Once a model has been generated, it will be possible to design and build adequate simulators so that the overall power subsystem can be more fully tested. Also detailed models of electrochemical batteries for both ac and dc conditions are required. Immediate problems of on-orbit failures suggest that the electrochemical system is poorly understood. As a result, power subsystem designs do not provide for all of the batteries' characteristics.

Power System Monitoring and Degraded System Management

Define, develop, and apply new and improved techniques for on-board monitoring and control of the power system and its components to reduce the complexity of managing degraded systems or components from the ground.

The sensor complement used for power system monitoring is inadequate. All too often we have too few diagnostic techniques to accurately isolate the causes of problems. More sensitive and expanded sensors are needed for monitoring battery cell voltages, ampere-hour integration, charge/discharge current, relay and power transfer switch states, solar array power, and load current sensing. Automatic power system control should be supported, e.g., MSFC's Programmable Power Processor (PPP) and JPL's Automated Power System Management (APSM).

New Component Development

Develop a variety of high voltage (150-400V), high power components including transistors, relays, capacitors, connectors and other distribution equipment. In addition, develop unique components for array current measurements, for battery state of charge determination, and for detection of and protection against faults.

The advent of high voltage, high power systems for the Solar Electric Propulsion Stage (SEPS), the Power Module, the Power Extension Package, and Erectable Space Platforms points up the need for components to operate at higher voltage and current levels. The SEPS solar array is configured with modules that operate at 196 volts at peak power, and these modules can be connected in series to provide higher voltages in integral multiples of 196 volts. The beginning of life (BOL) 31.6 kilowatt power level at the lowest operating voltage produces approximately 250 amperes. Transistors, relays, capacitors, connectors, and other distribution equipment must be developed to meet these voltage and current levels. In addition, power unique components are required to measure current on the solar array (because of the use of shunt regulators on the solar array to dissipate excess power), to measure battery state of charge, and to detect and protect against faults.

High Voltage (Kilovolt) Technology

Develop a complete and detailed design guide handbook and a detailed model procurement specification for high voltage (KV) component design, manufacture, test, and acceptance.

Numerous and varied high voltage designs are failing and/or are unreliable. In fact, failure of high powered traveling wave tube amplifiers was designated by a senior Air Force spokesman as the number one problem for communication satellites. All too often these failures could have been avoided by the application of the proper design, manufacturing, and test disciplines. Missing is a complete and detailed design guide (handbook) for high voltage equipment somewhat similar to the JPL Solar Cell Array Design Handbook.[7] Also required is a detailed model high voltage procurement specification. The design guide should provide a set of recommended hardware design

and analysis techniques and procedures. The model specification should contain detailed test techniques, methodology and acceptance criteria for piece parts, subassemblies, and top assemblies.

Reliable Solar Cell Interconnection

Develop specific techniques and tests for controlling solar cell and array manufacturing processes to assure reliable interconnection of the cells into arrays, addressing the integrity of both the solar cell contact and the interconnect attachment.

The failure of solar cell contacts is a recurring problem and reliable testing techniques are not available. Humidity tests currently in use are as questionable as they are diverse with respect to establishing contact integrity over extended shelf or orbital lifetimes. Simultaneously, life cycling in a thermal vacuum environment is both expensive and time consuming. Finally, inspection of contacts, joints (welded or soldered) and interconnectors on large arrays, where many thousands and even millions of attach points are required, is patently unreasonable. Various techniques such as infrared scanning, laser holography, X-ray, and resistivity measurements have been tried but these techniques are both expensive and inadequate.

Nickel-Cadmium Battery Manufacturing and Application Technology

Develop and apply electrochemical and physical analysis methods for better understanding of Ni-Cd cells in order to define the necessary requirements for optimization and control of the cell manufacturing process. Optimization of battery reconditioning methods would also be an anticipated result of this effort.

Recent and frequent incidences of on-orbit degradation and failure of nickel cadmium batteries indicate a lack of uniformity in the original product and a lack of understanding of the cor-

rect application. The specific need has been identified for nickel cadmium long life design criteria, process standardization, electrochemical quality analysis methods, and reconditioning methodology to enhance operational performance for ten or more years on orbit.

Substorm and Plasma Design Data

Enhance on-going spacecraft charging studies, including definition of the space plasma environment, improved simulation of the environment for ground testing of power systems, prediction of system or component performance, and definition of system and component design requirements.

The newly defined existence of plasma trapped in the Earth's magnetic field and its possibly catastrophic effect on high voltage, high power solar arrays points up an urgent need to adequately define the substorm environment so that solar arrays can be designed to survive this environment with minimum degradation. In addition, simulation of the space plasma environment must be developed for ground testing of effects on electrical power systems. A determination needs to be made of the energy profile, where it will flow, and how it will be dissipated in the spacecraft systems.

Engineering Data Base

Develop a documented and broadly distributed engineering data base for emerging technologies in order to more rapidly and more reliably transfer the technology into on-going programs.

Because of project pressures to utilize increased solar cell efficiency (latest cell technology), the cell and cover characterization data concerning radiation and lifetime performance has not yet been generated or verified. This design data is necessary for today's array designs.

The Ni-Cd battery has a solid data base, but little if any of this type data base is available for the Ni-H_2 cell. Until it is available, Ni-H_2 battery programs will be difficult to sell to flight projects.

Power MOS devices are currently available from the manufacturers, but there has been no effort to qualify these units for flight in spite of their switching and low gate power advantages. The big question is their radiation susceptibility.

Microprocessors are going to be necessary for housekeeping and management of power components within the power system. It is necessary to select universal types which are flight qualified.

There are presently few if any high voltage, high power devices which can meet present and future needs. A large technology development, including the associated data base, is needed. The rejection criteria for these devices must be formulated with a verification test program to guarantee high reliability parts in a new and difficult environment.

Rotary Joints for Power and Signal Transfer

Develop a combination rotary power and duplex transformer configured to provide transfer (between spinning and de-spun spacecraft sections, for example) of high power and high data rates with increased reliability and reduced noise.

High voltage, high power systems add a dimension to the past problem of transmission of 28 volt power and low level signals across a rotary joint. Possible techniques include rotary transformers, flexible harnesses, and slip rings for power and signals and rf and optical coupling for signals. Additional work must be done in this area both because of past failures and present needs.

On-Array Power Management

Develop components and designs to provide basic power management on the solar array rather than within the spacecraft in order to simplify the power system and to reduce the thermal requirements for the spacecraft.

On-array power management has been a requirement with little actual development having been accomplished. On-array power management is required to reduce the rotating interface complexity, to place the heat at panel surfaces having lightweight construction and small thermal mass, and to provide power management flexibility over individual string current, voltage and power sensing, spot thermal control, panel or string problems due to degradation or environmental interactions, and current control of array overpower or overvoltage conditions. The requirement suggests a need for advanced concept developments such as (1) three terminal solar cells, (2) photo-controllable cover slides, or (3) liquid crystal control covers.

CONCLUSIONS

The Flight Technology Improvement Workshop led to ten primary recommendations for power technology research and development to overcome past and current problems in spacecraft power and experiment/instrument power supplies.

Although the recommendations were developed in the context of near-term requirements and reflect currently unfulfilled technology needs, they also have merit with respect to far-term projections. That is, if the technology needs are not fulfilled, they will become significantly aggravated as higher power, longer life, more sophisticated spacecraft come into being.

ACKNOWLEDGEMENT

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